Remeshing free, graph-based FEM allows us to scale fracture simulations to very high resolution volumetric meshes at speeds faster than any other method present in literature.

Scalable Visual Simulation Of Brittle And Ductile Fracture

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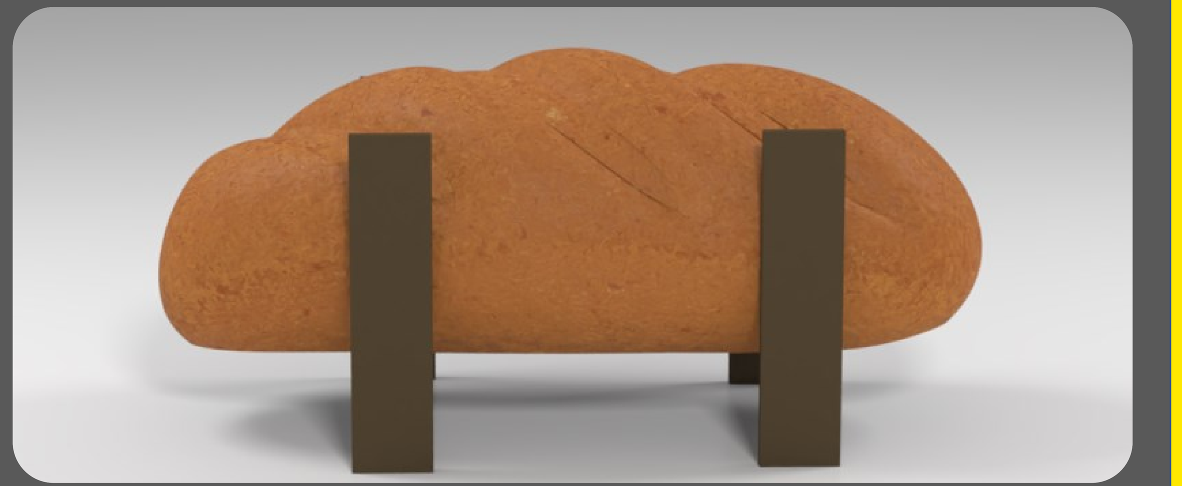
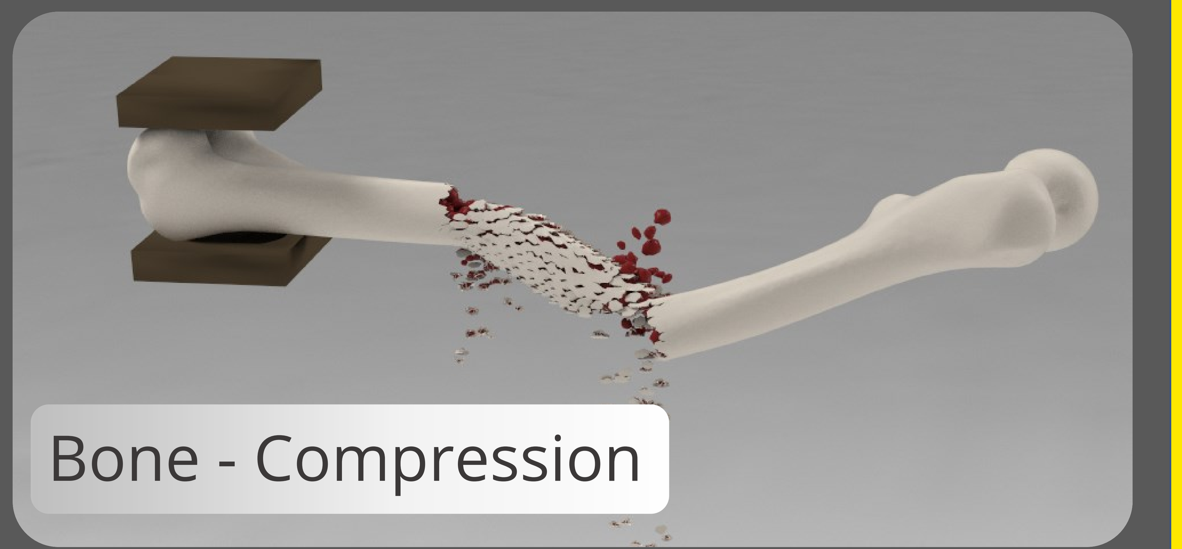
Results

Blue Jade Armadillo



Loaf of Bread



Bone - Compression

Bone - Shear

Full Paper Link
http://arxiv.org/abs/2103.14870

IIT Bombay

SIGGRAPH 2021

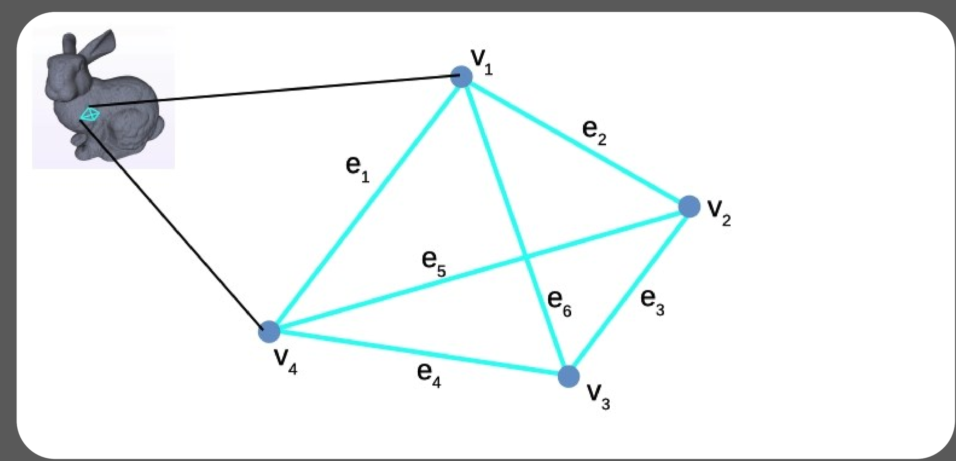
Video Link

Motivation

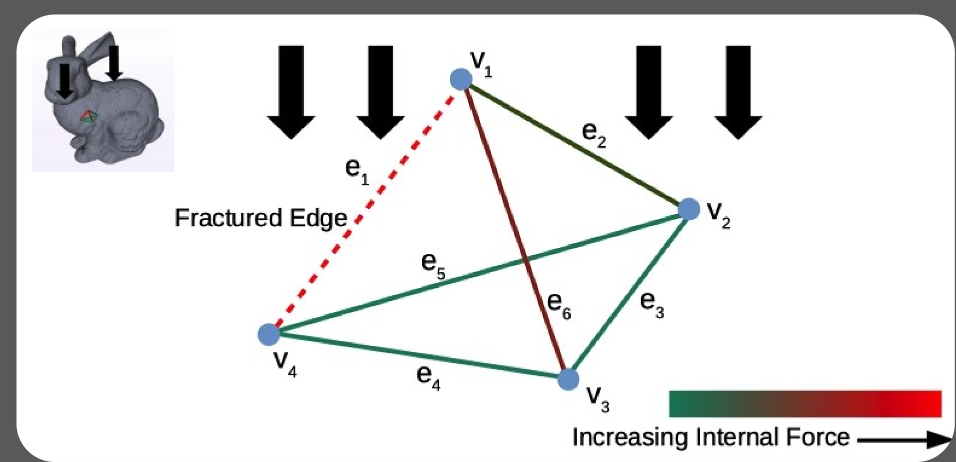
- FEM system matrix scales rapidly with increase in number of fracture fragments due to re-meshing [1].
- Other limitations in some methods include high computation cost [3] and presence of degenerate elements.

Solution

- Graph-based FEM [2] works on graph induced in a volumetric mesh.



- Hyper-elastic strain energy can be reformulated in terms of only edge lengths.
- Relabel the edges using a damage variable to mark them as fractured.



Visualization

- The computational volumetric mesh never needs to be remeshed, so the size of the system matrix never increases.
- The visualization surface mesh is remeshed, for rendering.

Algorithm

Algorithm 1: Remeshing-Free Graph-based Fracture

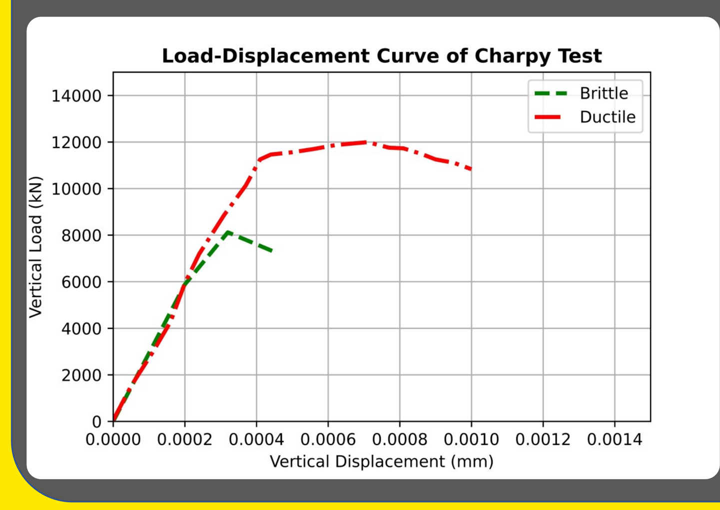
Initialize FEM simulation;
while *True* **do**
  for *each element in* $\mathcal{M}_c$ **do**
    Calculate stress along the edges σ_{mn};
    if $\sigma_{mn} > \sigma_{thres}$ **then**
      Label the edge as damaged;
      Remesh the surface of the corresponding $\mathcal{M}_v$;
    end
    Resolve all collisions with $\mathcal{M}_c$;
    Calculate impulse force due to collision;
    Add all external forces to the vertices of $\mathcal{M}_c$;
  end
  Build full system $[M]_{n_v \times n_v} [v]_{n_v \times 1} = [f]_{n_v \times 1}$;
  Solve for velocity vector $[v]_{n_v \times 1}$;
  for *each vertex in* $\mathcal{M}_c$ *and* $\mathcal{M}_v$ **do**
    Update position vector by $[x]_{n_v \times 1} += \Delta t \cdot [v]_{n_v \times 1}$;
  end
end

Validation

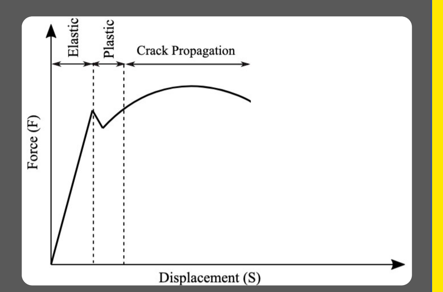
Charpy Test Configuration

Brittle Sample

Ductile Sample



Simulated



Ideal

References

1. Chitalu et al., Displacement Correlated XFEM for Simulating Brittle Fracture, Comp. Graph. Forum, 39:2 (2020), 569-583.
2. Khodabakshi et al., GraFEA: a graph-based finite element approach for study of damage and fracture in brittle materials, Meccanica, 51 (2016), 3129-3147.
3. Levine et al., A Peridynamic Perspective on Spring-Mass Fracture, In Proc. Of SCA'14, 47-55.